Table 2. Results from contingency analysis testing the hypothesis that the distribution of fish across habitats was the same during the day and at night. For species with p values < 0.10, habitat types with high contributions to the G statistic are listed. Up arrows indicate habitats that were over-represented and down arrows indicate habitats that were under-represented. Habitats were classified as either vegetation, reef, under crevice (hiding), or sand.

Species	G	p	Night	Day
Balloonfish	2.65	0.45		
Damselfish, bicolor	4.95	0.08	↑ hiding	
Damselfish, dusky	5.53	0.14		
Damselfish, sergeant major	2.26	0.52		
Damselfish, three spot	2.64	0.45		
Parrotfish, princess	0.42	0.81		
Parrotfish, redband	8.38	0.02	↓ reef, ↑ hiding	
Parrotfish, stoplight	5.92	0.12		
Parrotfish, striped	4.11	0.25		
Squirrelfish	11.90	0.001	↑ veg., ↑ sand,↓ hiding	↓ veg., ↓ sand
Squirrelfish, longjaw	16.72	0.001	↓ hiding	↑ hiding
Squirrelfish, dusky	6.14	0.10		
Squirrelfish, longspine	4.53	0.10		

Diel changes in the zooplankton assemblage over a Caribbean coral reef

Maria S. Calvi, Kathrine W. Manaras, Zoë M. McLaren, Winsor H. Lowe, and the 2000 Dartmouth FSP class

Abstract: Zooplankton may avoid visually feeding diurnal planktivores by taking refuge on the benthos during the day and migrating into the upper water column at night to feed. In support of this hypothesis, we found nighttime densities of zooplankton in the water column to be 50 fold greater than daytime densities in the backreef of Discovery Bay, Jamaica. Only two zooplankton taxa were found in day samples, while ten were found at night. Copepods accounted for 95% of total zooplankton density in both day and night samples. Excluding copepods from the analysis, total nighttime densities were still greater than daytime densities. Zooplankton in the water column during the night were on average 2.5 times larger than those found during the day. There was no difference in the size distribution of copepods in day and night samples.

Key Words: copepods, medusae, vertical migration

Introduction

Zooplankton associated with coral reefs face heavy predation from abundant filter feeders and planktivorous fish. The generally high diversity of reef-associated zooplankton species and the high number of reef species that produce pelagic larvae therefore suggests that some form of predator-avoidance mechanism must be used by these taxa. One potential avoidance mechanism available to zooplankton is diel vertical migration, where zooplankton avoid visual daytime predators by taking refuge in or on the benthos during the day and migrating into the upper water column at night to feed.

If zooplankton exhibit diel vertical migration in the backreef of Discovery Bay, Jamaica, we would expect to find more zooplankton taxa and more total individuals in the water column at night than during the day. Furthermore, if this predator avoidance response is greater for larger, more easily seen zooplankton, we would expect zooplankton found in the water column during the day to be smaller than those found during the night.

Methods

We collected zooplankton on 28 February 2000 along a 20 m transect running parallel to and approximately 20 m toward shore from the reef crest on the eastern side of Discovery Bay, Jamaica. The transect was located NNE (210°) of the door to the equipment cage at the marine station. Zooplankton tows were taken by snorkelers holding a plankton net (26 cm diameter, 153 μm mesh) at arm's length from the body, 20-40 cm below the surface, swimming out and back along the length of the transect. This resulted in 2.06 m^3 of water filtered per sample. Five replicate day samples were collected from 14:00 – 15:30 (25% cloud cover) and five night samples were taken from 22:00 – 22:30 (< 10% cloud cover, half-moon). Samples were rinsed from the net and immediately preserved with 10% formalin.

Zooplankton were counted and measured in Petri dishes with an inscribed grid using dissecting microscopes and a clear plastic ruler placed beneath the Petri dish. For all 10 samples (5 day, 5 night) the entire sample was counted. Lengths of observed size classes and number of individuals per size class of the following taxa were recorded: nauplii (Copepoda juveniles), Decapoda, Polychaeta, Isopoda, fish larvae, Mollusca larvae, Amphipoda, mysids, Appendicularia, cumacean shrimp and pelagic Gastrapoda. Due to their great abundance in samples from

Table 1. A comparison of zooplankton density between day and night tows on the back reef of Discovery Bay, Jamaica. Night and day densities (m^{-3} (SE)) were compared using one way ANOVAs. Where variances were unequal, Welch's ANOVA was used to test for the effect of time of day.

Taxa	Density (m^{-3})					
	Day		Night		$F_{1,8}$	p
Copepoda	11.6	(1.5)	528.9	(55.3)	87.4	0.001
Nauplii	10.2	(1.4)	10.4	(3.8)	0.0	0.964
Decapoda	0.0	(0.0)	43.8	(5.4)		d
Polychaeta	1.2	(0.5)	3.4	(0.9)	4.5	0.077
Isopoda	0.1	(0.1)	6.4	(2.2)		d
Fish larvae	0.0	(0.0)	6.5	(2.5)		d
Mollusca larvae	0.0	(0.0)	0.0	(0.0)		dn
Cnidaria	0.0	(0.0)	0.0	(0.0)		dn
Amphipoda	0.0	(0.0)	0.7	(0.5)		dn
Mysids	0.0	(0.0)	0.3	(0.3)		dn
Appendicularia	0.0	(0.0)	0.0	(0.0)		dn
Cumacean Shrimp	0.0	(0.0)	1.0	(0.7)		dn
Palagic gastropods	0.0	(0.0)	0.2	(0.2)		dn
Total	**20.7**	**(4.0)**	**600.3**	**(56.9)**	**103.3**	**0.001**
Total*	9.1	(2.9)	71.4	(7.7)	2.4	<0.001

* total excluding Copepoda

dn 3 or more replicates in day (d) and/or night (n) samples had densities of 0 individuals m^{-3}; analysis could not be performed.

previous years (Pickhardt et al. 1999, Chiavelli et al. 1998), copepods were assigned to three predetermined size classes: < 0.5 mm, 0.5 – 1.0 mm, and > 1.0 mm. Weighted mean size of individuals in each taxon was calculated for each sample using median values of each size category and the number of individuals in that category. Weighted mean size of all individuals in a sample, excluding copepods, was calculated by pooling all size classes and abundances across all taxa.

Night and day densities of each taxon and of total-taxa were compared using one-way ANOVA. Because copepods overwhelmed total-taxa comparisons, at 95% of the total samples, we also analyzed total-taxa densities excluding copepods. We used Student's t-tests to examine differences between day and night samples in weighted mean size of individual taxa and weighted mean size of all taxa excluding copepods. Difference in the size distribution of copepods in day and night samples was examined using Chi-Squared contingency analysis.

Results

Zooplankton densities in the Discovery Bay backreef were approximately 50 times higher at night than during the day (Table 1). Copepod density was the highest of all taxa in both day and night samples and was significantly higher at night than during the day. Total zooplankton density excluding copepods was also higher at night (Table 1). Additionally, there was a strong trend towards higher polychaete density at night than in the day (Table 1). Out of the ten taxa found in all samples, two were found during the day, all ten were found at night, and two overlapped

Table 2. A comparison of the length of zooplankton between day (n = 5 tows) and night (n = 5 tows) on the back reef of Discovery Bay, Jamaica. Mean lengths are weighted by the number of individuals in each size class. A t-test was used to test for the effect of time of day.

Taxa	Length (mm)							
		Day			Night			
	N	Mean	(SE)	N	Mean	(SE)	T	p
Nauplii	5	0.29	(0.02)	4	0.43	(0.09)	-1.58	0.138
Decapoda	0			5	1.46	(0.16)		dn
Polychaeta	4	0.67	(0.21)	5	4.36	(1.36)	-4.03	0.005
Isopoda	1	3.5	(0)	5	1.05	(0.14)		dn
Fish Larvae	0			5	2.57	(0.36)		dn
Amphipoda	0			2	1.55	(0.05)		dn
Mysids	0			1	1.08	(0)		dn
Total*		0.76	(0.32)		1.96	(0.35)	-3.60	0.001

* total excluding Copepoda

dn 4 or more of the day (d) or night (n) samples contained 0 individuals and therefore, a statistical test was not conducted

between day and night samples (Table 1).

The mean length of all zooplankton, excluding copepods, was approximately 1.5 times larger in night samples than in day samples (Table 2). Polychaetes found at night were approximately six times larger than those found in the day, while nauplii did not differ significantly in length between day and night (Table 2). The distribution of copepods among designated size classes did not differ between day and night (chi-square test, df = 2, chi-square = 0.77, Figure 1).

Discussion

Our results provide evidence for the use of diel vertical migration as a predator avoidance mechanism by zooplankton in the backreef of Discovery Bay, Jamaica. Nighttime zooplankton samples exhibited higher zooplankton densities, more zooplankton taxa and larger individual zooplankton than daytime samples. These results document a predator avoidance behavior that can have important implications for distribution and population regulation among taxa that are planktonic or have planktonic larvae and among planktivorous species feeding on these taxa. Planktivorous fish densities may be limited by the number and density of day-active zooplankton, which, in turn, may be limited by the level of fish predation and the ability to adopt nocturnal activity patterns. The distribution of species with planktonic larvae may also be controlled by planktivore densities and the capacity for nighttime activity

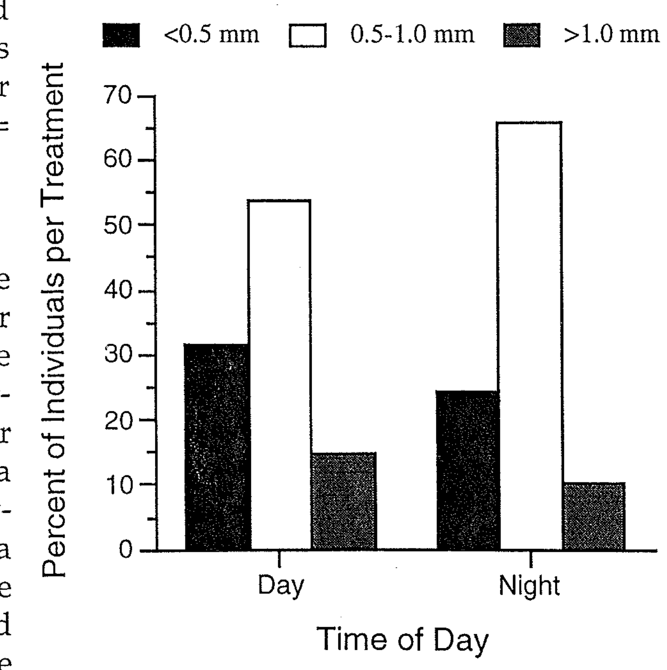

Figure 1. A comparison of the size distribution of copepods between day (n = 5 tows) and night (n = 5 tows) on the back reef of Discovery Bay, Jamaica. A chi-squared analysis shows no significant differences.

among larvae.

It is notable that we found an extremely high density of medusae in both the day and night samples. It is possible that the low densities of all taxa in both day and night samples relative to those found in past studies (Chiavelli et al. 1998, Pickhardt et al. 1999) could be explained by intense feeding by these medusae in the sampling location.

Literature Cited

Chiavelli, D. S., and The 1998 Dartmouth FSP Class. 1998. Diel changes in the zooplankton assemblage over a Caribbean coral reef. Pp. 159-161 *in* Dartmouth Studies in Tropical Ecology 1998. Dartmouth College: Hanover, NH.

Pickhardt, P.C., A.G. Blundell, and The 1999 Dartmouth FSP Class. 1999. Diel changes in the zooplankton assemblage near a Caribbean reef crest. Pp. 152-154 *in* D. Hogan and M. Babineau editors, Dartmouth Studies in Tropical Ecology 1999. Dartmouth College: Hanover, NH.